MODIS DATA STUDY

TEAM PRESENTATION

January 12, 1990

AGENDA

1. Data Flows for Routine MODIS Standard Data Product Generation (Ardanuy)
   - Level-1 to Level-4
   - Level-1A
   - Level-1B
   - Level-2
   - Level-3

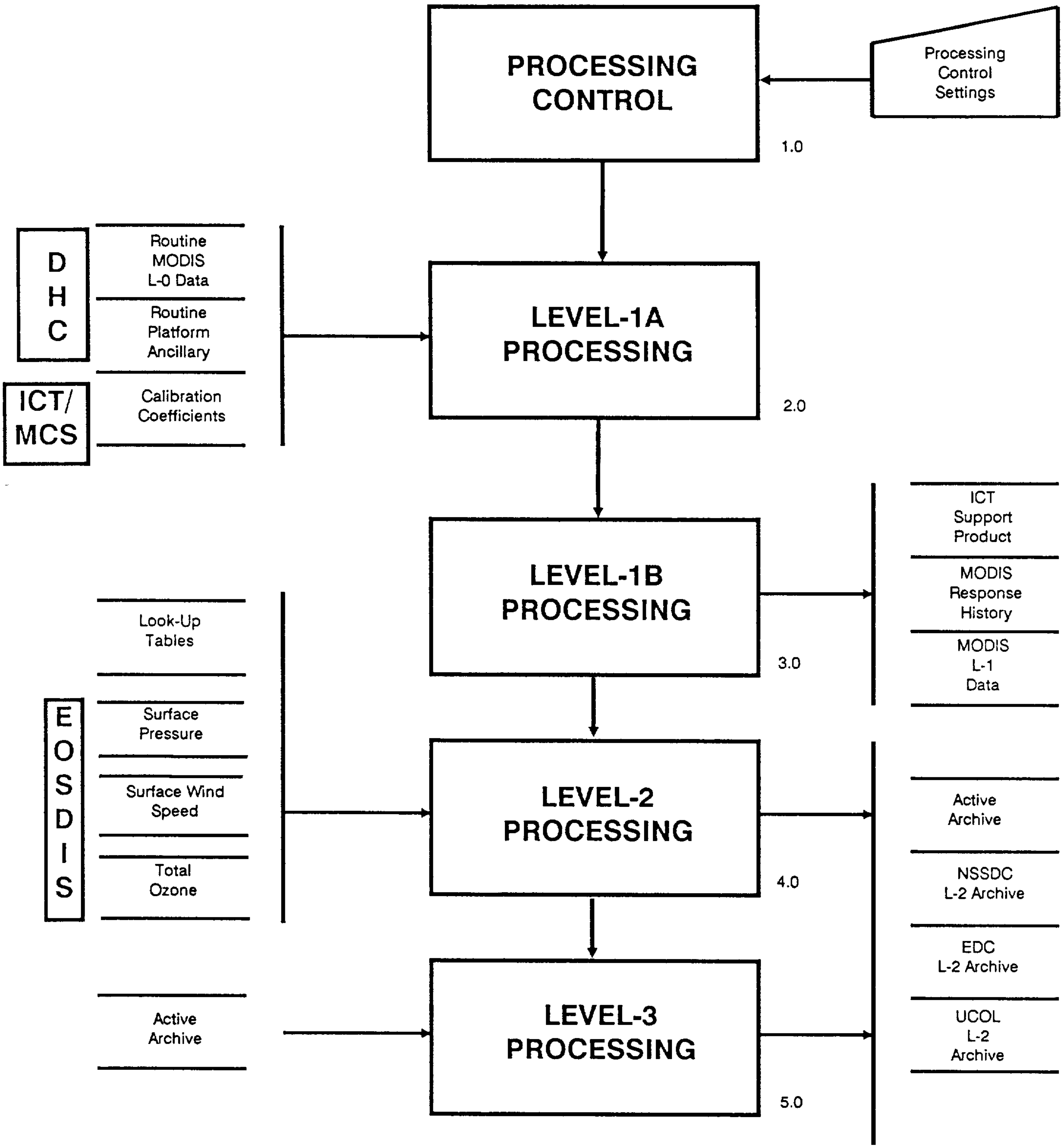
2. Estimation of Processing Requirements; Application to Aerosol Size Distribution (Andrews)

3. Method 2 for Aerosol Size Distribution Processing Estimation (Hoyt)

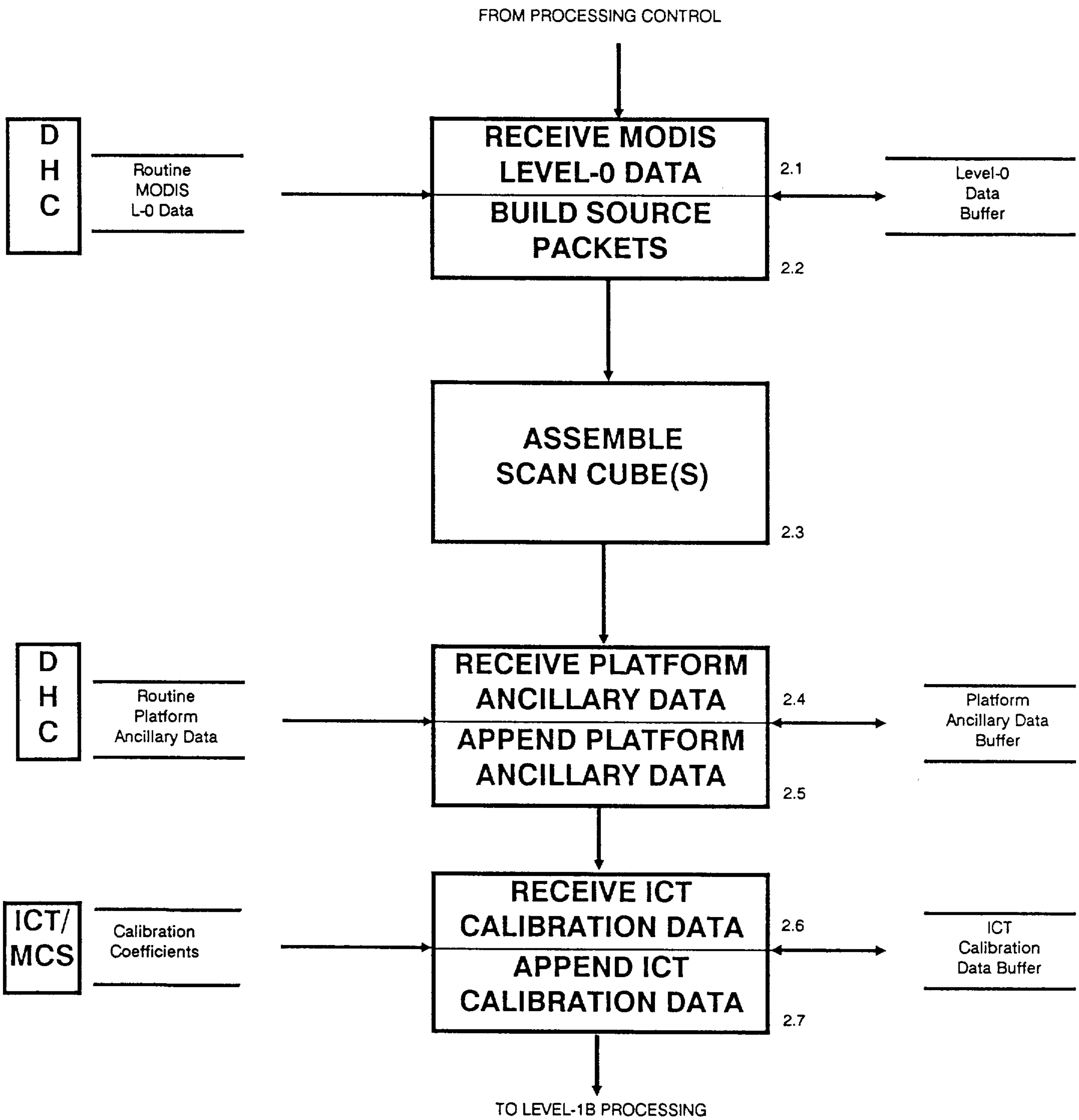
4. Requirement for Processing Conglomeration of MODIS Scans Simultaneously (Ardanuy)

5. Revised Requirements for Atmospheric Corrections Needed to Produce Level-2 Land-Leaving Radiances (Riggs)

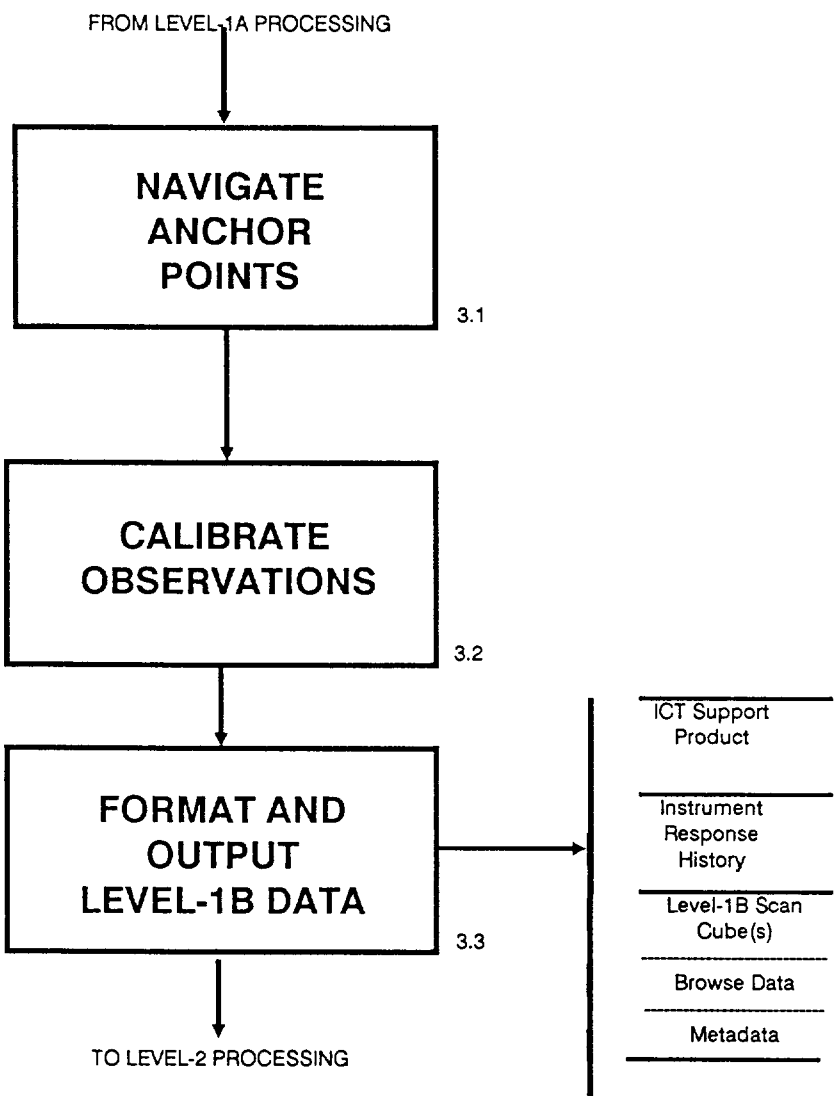
DATA FLOWS FOR ROUTINE LEVEL-1 TO LEVEL-4 MODIS DATA PROCESSING



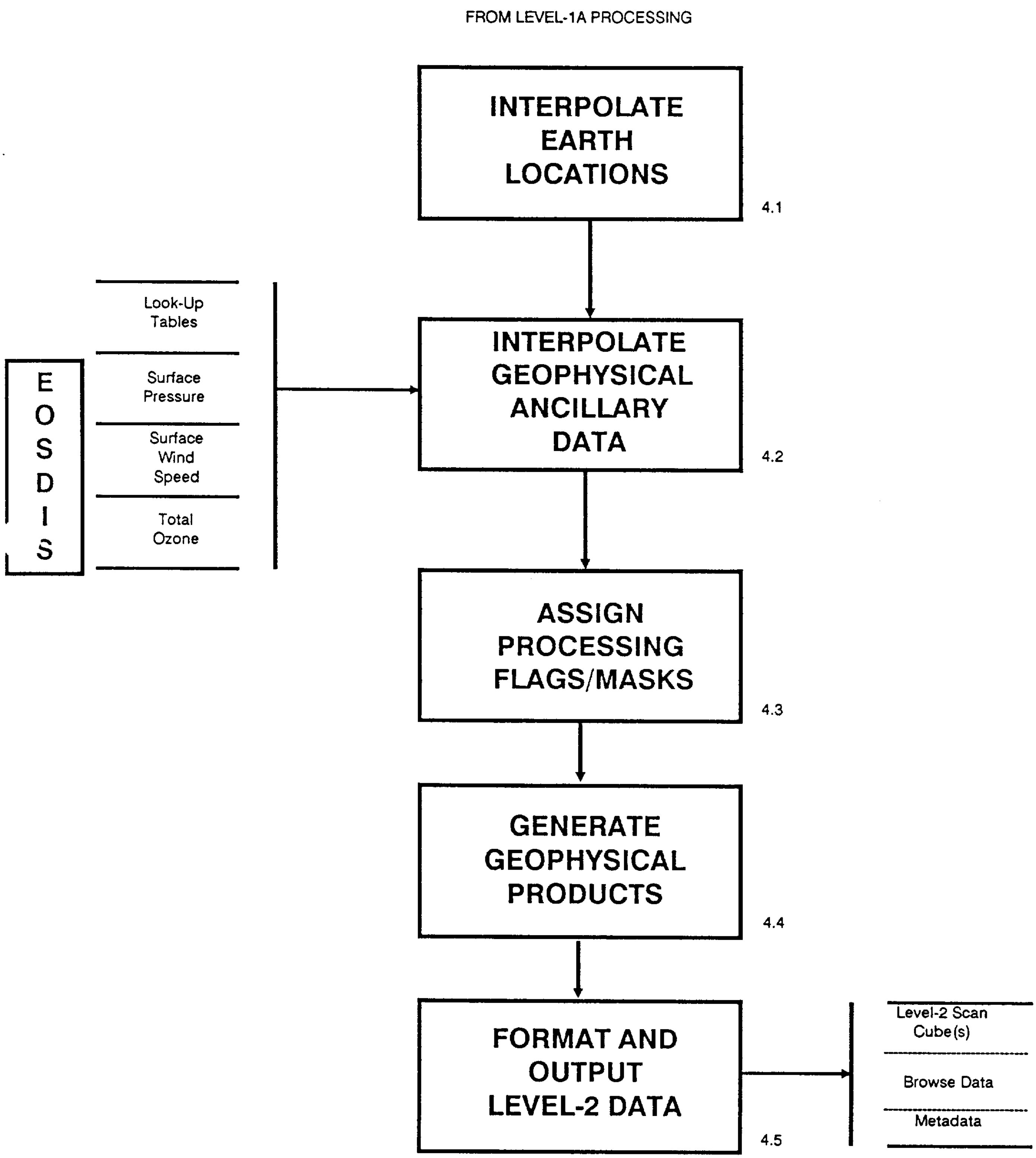
DATA FLOWS FOR ROUTINE LEVEL-1A MODIS DATA PROCESSING



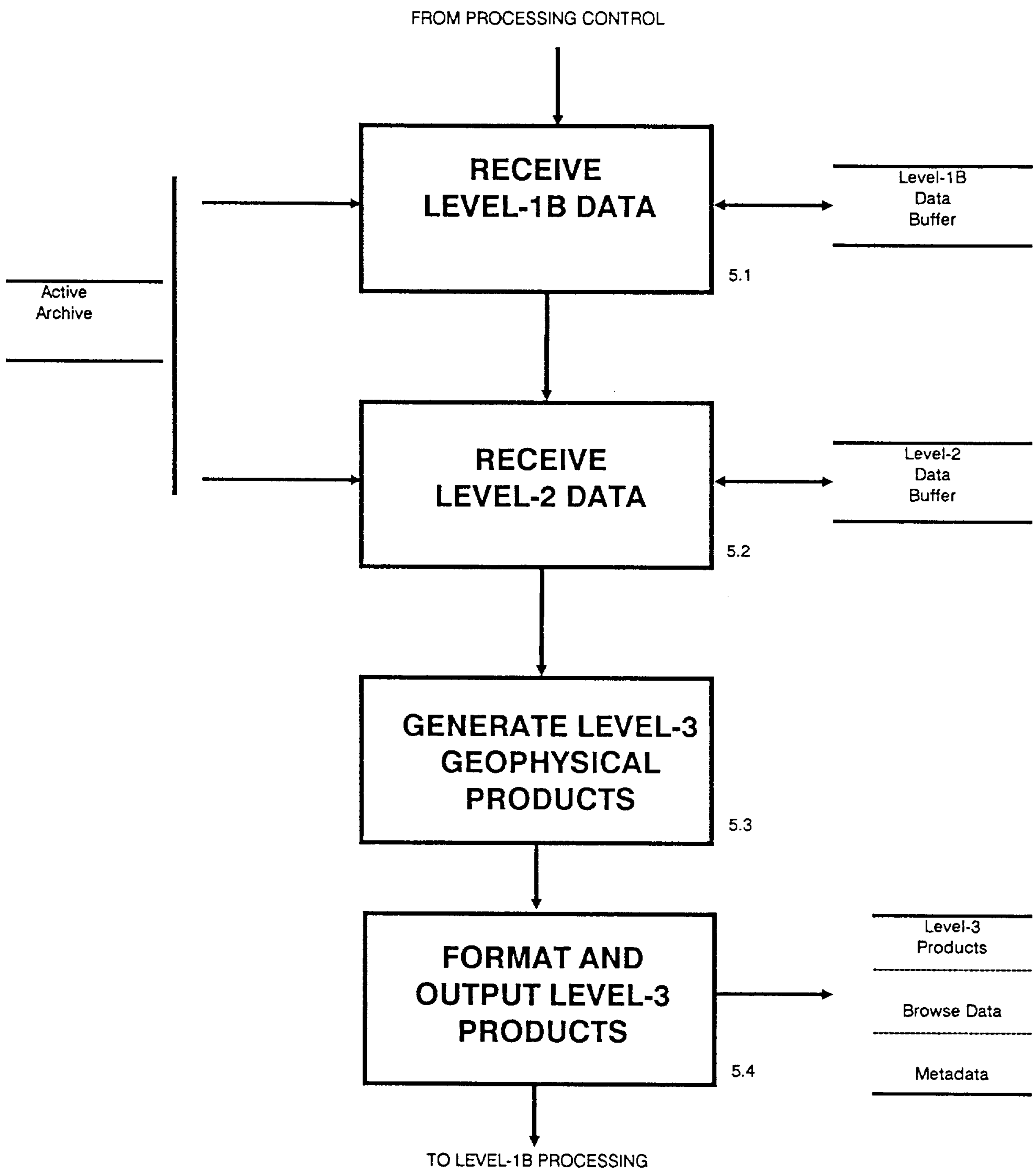
DATA FLOWS FOR ROUTINE LEVEL-1B MODIS DATA PROCESSING



DATA FLOWS FOR ROUTINE LEVEL-2 MODIS DATA PROCESSING



DATA FLOWS FOR ROUTINE LEVEL-3 MODIS DATA PROCESSING



Estimating Processing Requirements and A Preliminary Result for One Algorithm

This is a short discussion of one method we propose to use to estimate the processing requirements to generate MODIS data products. A preliminary result for one algorithm is presented to show how this method is applied. The algorithm is that of Dr. King to determine the aerosol size distribution. For this algorithm the processing estimate is uncertain by a factor of ten.

Method

It is relatively straight-forward to estimate the operations erformed in an existing algorithm. A listing of the program is examined to simply count the numbers of the various arithmatic operations. Only the computational portion of the algorithm is used, i.e., there is no estimate of the CPU required for I/O.

The operations are split into two categories. Simple operations are the four simple math operations +, -, X, and /, plus exponentials, assignments, and IF statements. Each of these functions can be taken to be <u>one</u> floating point operation (FLOP). The more complex operations will include trig functions, logarithms, square root, etc. These complicated operations can be estimated as <u>ten</u> FLOP. Any existing code can be analyzed to estimate the number of FLOPs required for that algorithm. If the algorithm works on a single pixel, the required CDHF processing power is estimated by taking the number of pixels/second to which the algorithm is applied. Factors such as cloud cover and resolution must be considered. The processing estimate can be checked by running the actual code and comparing the estimated and observed execution time.

Analysis of RADINV

Dr. King has supplied a working version of the program RADINV, which determines the aerosol size distribution based on optical depth versus wavelength data. The algorithm does an iterative parameter determination which is essentially equivalent to a recursive least-squares minimization. This involves setting up and inverting a matrix up to 3 X 8 times. The program has been analyzed in terms of the processing done in each iteration and the processing done outside of the nested loops. In each case, the number of operations depends on the number of wavelengths, N. There are no significant "complex" operations in this algorithm. The calculation of the matrix and the parameter determination by matrix inversion requires $548 + N\{ 31 + N[60 + 10N] \}$ simple operations which may be done up to 24 times. The setup and control of the process requires $685 + N\{ 876 + N[5 + 2N] \}$ additional operations. The number of operations increases as the third power of the number of input wavelengths and directly with the number of iterations. The total number of operations as been calculated for 8 and 24 iterations with 6 or 10 input wavelengths. The totals are

8 and 6 --> 47,000; 8 and 10 --> 147,000; 24 and 6 --> 128,000; and 24 and 10 --> 416,000 operations for each point at which the calculation is done. This implies that the estimate of the requirement for a single pixel is uncertain by a factor of 3 to 10.

It has not been determined how often this algorithm will be exercised; i.e., for what fraction of the pixels the aerosol size distribution is determined. The determination can be done whenever the aerosol optical depth is determined. On the other hand, it is not expected that the size distribution will vary much on small spatial scales, so it may be adequate to calculate the size distribution every 100 km. (The aerosol optical depth can only be determined over clear pixels and the size distribution will only be determined for clear pixels.) It is possible to combine all of the uncertainties in a single equation for the processing power that will be required. The result is:

$$P = \# * \% * (685 + 548*I + N*[876 + 31*I + N\{ 5 + 60*I + 2*N + 10*N*I\}])/A$$

where
- # = number of fields of view per second
- % = the fraction of clear pixels for which optical depth is determined
- N = the number of wavelengths
- I = the number of iterations
- A = the number of pixel in the resolution cell of the product.
- (The units on P will be FLOPS)

For #=12,000, %=0.5, N=6, I=8, and A=100, i.e. 8 km resolution, P= 5.6 MFLOPS. This is the power required. If we assume 20% efficiency and include the factor of six for reprocessing, this product will require 170 MFLOPS for the above assumptions.

MODIS ALGORITHM AND DATA PRODUCT SIZING SPREADSHEET: OUTPUT SEC

PART 1: MODIS DESCRIPTIVE INFORMATION:

Name of data product:	Aerosol Size Distribution (
Product ID code:	
Spreadsheet level and ID	2 22
Scientific discipline:	Atmosphere/aerosols
Code developers: 1	Dr. Tanre
2	Dr. King
3	Dr. Gordon (Angstrom alpha
4	
Latest scientific ref.:	
Last spreadsheet mod.:	01/11/90 04:34 PM
Responsible person:	D. Hoyt

PART 2: DADS/CDHF DATA STORAGE REQUIREMENTS (Gb):

Output data volumes:	OFF-LINE	ON-LINE
Level 1A:	0.000	
Level 1B:	0.000	
Level 2:	99.589	
Level 3:	99.589	
Level 4:	0.000	
Browse:	1.992	
Metadata:	0.201	
Total:	201.371	

PART 3: CDHF CPU REQUIREMENTS:	Method 1	Method 2
Level 1A:	0.000	0.000
Level 1B:	0.000	0.000
Level 2:	43.039	41.836
Level 3:	10.760	10.459
Level 4:	0.000	0.000
Browse:	1.076	1.046
Metadata:	0.055	0.053
Total:	54.929	53.395

PART 4: LINES OF CODE REQUIREMENTS:

Computer language:	Fortran
Lines of code:	
Computer memory required:	

PART 5: FUTURE EXPANSION

MODIS ALGORITHM AND DATA PRODUCT SIZING SPREADSHEET: INPUT SECT

PART 1: DATA ACQUISITION VOLUMES

MODIS-N

Bits/pixel	12

Pixels/scan	1582
Detectors/scan at 1 km.	8
Scans/orbit	5840
Orbits/day	14.56
Bits/day	1.3E+10
Bytes/day	1.6E+09
Duty cycle for visible channels	0.5
Duty cycle for thermal channels	1
Number of 1 km. visible channels	12
Number of 0.5 km. visible channels	8
Number of thermal channels	16
Auxillary overhead	1.1
Single channel (1 km) daily giga-pixels	0.593
Single channel (0.5) daily giga-pixels	2.371
Single thermal channel daily giga-pixels	1.186
Total visible (1 km) daily giga-pixels	7.114
Total visible (0.5) daily giga-pixels	18.969
Total thermal channels daily giga-pixels	18.969
Total daily giga-pixels	45.052
Total daily gigabits	540.626
Total daily gigabytes	67.578

PART 2: MODIS-T

Bits/pixel	12
Pixels/scan	1007
Detectors/scan at 1 km.	32
Scans/orbit	1213
Orbits/day	14.56
Bits/day	6.8E+09
Bytes/day	8.5E+08
Duty cycle for visible channels	0.5
Number of 1 km. visible channels	32
Auxillary overhead	1.1637
Single channel (1 km) daily giga-pixels	0.331
Total visible (1 km) daily giga-pixels	10.597
Total daily giga-pixels	10.597
Total daily gigabits	127.158
Total daily gigabytes	15.895

PART 3: GENERAL ASSUMPTIONS:

Fraction of earth that is land:	0.30
Fraction of earth that is ocean:	0.70
Mean cloud cover for earth:	0.50
Maximum fractional computer utilization:	0.70
Number of expected re-processings:	2
Fraction of oceans which are case 1:	0.05
Fraction of oceans which are case 2:	0.95
Fraction of land that are deserts:	0.25
Fraction of land with dark vegetation:	0.35

PART 4: COMPUTATIONAL TIMES AND FLOATING POINT OPERATIONS

MACHINE: Cray Y-MP	ops.	micro-sec
Addition	0.83	0.0012
Subtraction	0.69	0.0015
Multiplication or do-loop	0.97	0.0041
Division	1.52	0.0132

Power	1.52	0.0774
Sine	7.86	0.0956
Cosine	8.00	0.0956
Tangent	9.10	0.0637
Arc-sine	8.00	0.1183
Arc-cosine	8.00	0.1183
Arc-tangent	8.00	0.0819
Logarithm	7.70	0.0442
If-statement	0.97	0.0030
Absolute value	0.12	0.0006
Square root	2.64	0.0132
Integer value	0.42	0.0021
Exp()	5.56	0.0278
Read input (about 200 MBps)	1.02	0.0051
Write output (about 200 MBps)	1.02	0.0051
Linpack mflops rating for above computer:		195

MODIS ALGORITHM AND DATA PRODUCT SIZING SPREADSHEET: COMPUTATIO

PART 1: WIDELY USED GENERAL UTILITIES:

Computations (operations/pixel and microseconds/pixel):

Earth location of pixel:		
without DEM (N-7 model):	271.3	1.999
with DEM:	542.7	3.998
for MODIS-N (1 wavelength p	16.9	0.124
for MODIS-T (1 wavelength):	8.5	0.062
Solar zenith angle vs.location:	51.5	0.610
Solar azimuth angle vs. location:	25.1	0.241
Satellite zenith angle vs. location:	51.5	0.610
Satellite azimuth angle vs. location	25.1	0.241
Land/ocean mask:	3.9	0.012
Desert/non-desert mask:	3.9	0.012
Ice/snow mask:	3.9	0.012
Surface roughness mask:	3.9	0.012
Case 1/2 water mask:	3.9	0.012
Sun glint mask:	3.9	0.012
Cloud mask:	19.9	0.130
One time rectification of all images	151.8	1.298
Rectification to Level 3 applied:	2.5	0.004
Re-mapping to grid (2-D interpolatio	11.6	0.061
Atmospheric correction over ocean:	129.8	0.935
Atmospheric correction over land:	259.7	1.870
Weekly average from daily values:	7.3	0.022
Maximum of daily values in a week:	27.3	0.050
Monthly average from daily values:	27.3	0.050
Monthly average from weekly values:	4.8	0.018
Seasonal average from monthly values	4.8	0.018
Yearly average from monthly values:	11.5	0.028

PART 2: COMPUTATIONS OF CDHF CPU REQUIREMENTS:

Computations (ops/pixel and micro-sec/pixel):	ops.	times
Number of aerosol optical depths use	6	6
Fraction of pixels analyzed:	0.005	0.005
Angstrom alpha using N lambda's (Kin	56.7	0.642
No. of Lagrangian tests (max):	13	13

No. of error check cycles (max):	8	8
No. of Lagrangian tests (probable):	2	2
No. of error check cycles (probable)	2	2
No. of initial power laws:	3	3
Calculate 5 by 5 matrix:	24.3	0.038
Invert 5 by 5 matrix:	225.0	0.395
Calculate aerosol tau's:	192.5	2.048
Convergence test:	11.6	0.530
DNDLGR (N parameters):	4215.8	20.657
Weekly means:	7.3	0.022
Rectification/re-mapping to generate	72.2	0.369
Computations (gigi-ops/day and cpu-hrs/day):		
Input N aerosol optical depths:	43.5	0.060
Compute Angstrom alpha coefficient:	29.1	0.061
Compute d(n)/d log(r); N size parame	916.6	1.248
Output Angstrom coefficient:	8.3	0.011
Output N size parameters:	87.1	0.121
Total of above:	1084.6	1.502
Estimate of mflops rating required:		
Raw computations:	12.553	12.202
With fractional computer utilization	17.933	17.432
With re-processings:	53.798	52.296
Implied mflops rating:	53.798	52.296

PART 3: COMPUTATION OF OFF-LINE STORAGE REQUIREMENTS:

Number of MODIS-T Level 2 variables:	0
Number of MODIS-N Level 2 variables:	14
MODIS-T data volume (Gb/day):	0.000
MODIS-N data volume (Gb/day):	99.589
Other Eos data volume (Gb/day):	0.000
Non-Eos data volume (Gb/day):	0.000
Total off-line data storage per day:	99.589

PART 4: REFERENCES AND COMMENTS:

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Requirement for Processing Conglomerations of MODIS Scans Simultaneously

Twelve-bit data from the MODIS instruments will initially be packed into virtual source packets, segmented into packets for transmission to the ground segment, combined on the ground into source packets, then combined into complete scans of data.

Memory requirements for these complete scans are on the order of (to around ±10%):

	Megabits/scan	Megabytes/scan (with 10% ovhd)	Scan Period (sec)
MODIS-N Night	2.4	0.3	1.02
MODIS-N Day	12.8	1.8	1.02
MODIS-T Day	13.6	1.9	4.75

The general processing requirement for MODIS data, given an analysis of the Level-2 data product algorithms, is for computations on a pixel-by-pixel (or small group of pixels) basis. Of course, efficient processing may dictate that large sets (vectors) of identical computations be carried out simultaneously. This suggests that the minimum processing granule for MODIS data processing may be a complete scan of data. Including the storage for the observations in a scan, the processing code, ancillary data, look-up tables and constants, and output arrays, the maximum storage requirements for internal fast memory would conservatively seem to be less than ten megabytes.

However, there will likely be substantial coprocessing between AIRS/AMSU temperature, moisture, and other trace gas constituent profiles and the higher-spatial resolution MODIS measurements. The AMSU footprint is approximately 50 km at nadir, and joint AIRS/AMSU retrievals will be performed for this spatial scale. To combine the AIRS/AMSU and MODIS-N data at Level-2, two requirements must be met:

1. Sets of approximately six MODIS-N scans must be processed jointly together, so that the same ground coverage is available for MODIS-N as for AMSU. When the AMSU scan boundary falls in the middle of a MODIS-N scan, this scan might have to be partitioned into two different bundles, perhaps redundantly. The result is an increase in the internal storage requirement, from 1.8 megabytes of MODIS-N data to about 11 megabytes (Level-0 equivalent). Added to this are the Level-1B and -2 products and the other memory resident material. Perhaps a requirement of 25 megabytes might result. (Storage could be saved by decoupling the higher-resolution 214 and 428 m reflected bands and processing those separately, though this would add an additional complication.

2. The specific scans to be assembled must be chosen based on the scan timing from AMSU. Though this is a requirement at MODIS Level-2, we anticipate performing the Level-1 and Level-2 MODIS data processing concurrently, and without interruption, without the need for interim reads/writes to and from an external storage device. Therefore, the timing of the AMSU scans must be available for the MODIS-N Level-1 processing. Ideally, this would occur automatically as a part of the platform ancillary data (if AIRS and AMSU scans are synchronized, then this data might already be required on the platform).

Revised Requirements for Atmospheric Corrections Needed to Produce Level-2 Land-Leaving Radiances.

Problem Statement

To determine the land-leaving radiance component from the radiance signal measured by the sensor requires that atmospheric effects in the signal be corrected for. Developing atmospheric corrections for use over terrestrial surfaces with sensors such as the AVHRR, TM, Landsat MSS, and SPOT is an active area of research. Presently there are no specific atmospheric correction algorithms defined for use with MODIS-N data. Presented here is a basic framework describing the problem of correcting for atmospheric effects and possible approaches to their solution derived from the literature (see bibliography). The purpose of the framework is to serve as a beginning for developing the atmospheric corrections required to produce land-leaving radiances and identify sources of non-MODIS data that may be required. The atmospheric correction algorithm is expected to evolve as MODIS Science Team members turn their efforts towards the difficult problem of atmospheric correction in the pre-launch phases.

Furthermore, atmospheric correction of the MODIS radiances over terrestrial surfaces will in turn result in an increase in the performance requirements for the MODIS data processing. A definitive and comprehensive sizing of a reasonable atmospheric correction over land is therefore a key element in the derivation of performance requirements for the MODIS Level-2 product generation. Thus, the following atmospheric correction algorithm directly supports these sizing studies.

Radiance at the Sensor

Radiance reaching the sensor is composed of two basic components; 1) radiance reflected directly from the surface (direct beam) and 2) path radiance, caused by scattering of radiation within the atmosphere. Only the direct beam reflected from the surface contains information about the surface. The amount of reflectance from the surface is determined by surface characteristics and is attenuated by the atmosphere. The contribution of path radiance to the signal sensed at the sensor is dependent on atmospheric characteristics, principally, aerosol scattering, and Rayleigh scattering. Path radiance blurs and confounds the direct beam. Correcting for atmospheric effects on transmission of the direct beam, and for the contribution of path radiance, results in a land-leaving radiance, that ideally contains only information about surface characteristics. The situation is illustrated in Figure 1, and can be expressed as:

$$L = (L_s\ t_s)/\pi + L_p \qquad (1)$$

where

L - radiance measured at sensor
L_s - reflectance from the surface (i.e. direct beam)
t_s - transmittance of direct beam through atmosphere
L_p - path radiance

From the perspective of remote sensing of the terrestrial environment, where the radiance sensed by the sensor is to be used to study surface features, one would like to solve for L_s in Eq.1, but this requires that L_p be known, specifically, which it generally is not. In essence, L at the sensor is a function of two unknowns; surface reflectance, Ls, and path radiance, Lp. The nature of these unknowns and approaches to solving for them are discussed below.

Approaches to Atmospheric Corrections

Path radiance, L_p, and L_s cannot be solved for simultaneously, one or the other must be known or assumed. Approaches to atmospheric corrections for land surfaces being applied to AVHRR, Landsat MSS, and other sensors are a very good source for envisioning how the atmospheric correction problem may be approached for MODIS-N. Also, the methods used by oceanographic scientists to correct satellite images for atmospheric effects over oceans are useful to the development of atmospheric corrections over land. Most atmospheric approaches require a knowledge of surface features and/or aerosols present in an image and involve interaction with the image or images. What becomes apparent from these studies is that data external to MODIS will be required to correct for atmospheric effects.

Atmospheric Effects

Three atmospheric effects; Rayleigh scattering, aerosol scattering, and ozone absorption, and their determination in relation to Equation 1 are briefly considered here. Possible sources of data needed for determining the effects of these three atmospheric constituents are given in Table 1. No accuracy requirements of these data for correcting over land are specified, but accuracies for corrections over oceans have been (see MODIS Data Study Team Presentation, 22 December 1989. At present, it appears that the largest unknown in the atmospheric corrections is in the determination of the amount of aerosols in the atmosphere.

Path Radiance (Aerosols)

Path radiance, L_p, is caused by Rayleigh and aerosol scattering in the atmosphere, and is added to the signal sensed by the sensor. Rayleigh scattering is relatively invariant in time and space and is discussed in greater detail below (See Rayleigh scattering below). Aerosol caused scattering is the greatest unknown in determining L_p. Though the radiative transfer characteristics of aerosols (i.e. single scattering albedo, and phase function) are well defined, a major difficulty in correcting for their effects, is determining the physical amounts of aerosols present in the atmosphere (Y. Kaufman). Aerosols are variable both temporally and spatially, making it difficult to determine physical amounts present unless actually measured, or the aerosol climatology of a region is known with enough certainty to estimate aerosol content at particular times. If some determination of aerosol optical thickness, τ_A, can be made e.g. determined from the aerosol climatology of a region, and a satellite image in that region containing a known surface feature, then corrections are possible (Kaufman and Sendra, 1988). One possibility is that if the aerosol optical thickness τ_A can be determined then the scattering and attenuation functions can be calculated. It may be possible to use ground visibility readings from reporting stations to determine τ_A, such data may come from the National Meteorological Center (NMC), but this possibility needs to be evaluated by the MODIS Science Team members.

To demonstrate the potential effect of aerosol optical thickness, under clear and hazy atmospheric conditions, τ_A was calculate by two methods for clear and hazy conditions. The Angstrom formula:

$$\tau_{A\lambda} = \beta \lambda^{-\alpha} \tag{2}$$

where,

α = 1.0, a value typical of continental aerosols
β = turbidity coefficient related to turbidity
β = 0.102 for clear, 25 km visibility
β = 0.43 for hazy, 5 km visibility

and, from Singh and Saull (1988) aerosol optical thickness for an average continental type was calculated as:

$$\tau_{A\lambda} = 0.1\lambda^{-1.3} \tag{3}$$

Both methods produced similar curves (Figure 2) for the clear atmosphere case. The apparent need for an aerosol correction is demonstrated by the relatively large difference in aerosol optical thickness between clear and hazy conditions.

A technique for determining τ_A that will yield reasonable amounts and provide for acceptable data products will need to be determined. It may be possible to obtain τ_A from MODIS-N as aerosol optical depth has been listed as a potential Atmospheric Core Data Product. Other sources for ozone data are listed in Table 1.

Surface reflectance (direct beam)
The direct beam reflected from the surface is dependent on total incident irradiance and surface reflectivity, and is attenuated in the atmosphere by aerosols and Rayleigh. Attenuation of the direct beam can be expressed as an extinction function:

$$L_s = F_o \ \rho \ e^{-(\tau R + \tau A)/\cos\theta} \tag{4}$$

where

F_o = total irradiance on the surface (direct + diffuse)
ρ = surface spectral reflectivity
τ_R = Rayleigh optical thickness
τ_A = aerosol optical thickness
θ = angle for path length, sun zenith angle for incoming beam, view angle for reflected beam

In order to determine reflectance from the surface in the above manner the surface spectral reflectance and total incident irradiance would need to be determined. Total irradiance is the sum of direct irradiance and diffuse irradiance. Diffuse irradiance is caused by scattering of incoming solar radiation by the atmosphere. Total irradiance could be determined with data inputs of extraterrestrial irradiance (possibly in look up tables), and optical thicknesses, τ_R and τ_A, used to determine atmospheric attenuation of the beam and path radiance contributions i.e. diffuse irradiance on surface.

Rayleigh scattering

Rayleigh (or molecular) scattering is inversely related to the fourth power of the wavelength, is relatively invariant in time and space, and can be accounted for in a fairly straight forward manner. The calculation of Rayleigh optical thickness, τ_R, is required. Rayleigh optical thickness depends on surface pressure and has been derived for a standard atmosphere by several authors. Derived equations for Rayleigh optical thickness at standard pressure, τ_{Ro}, require only wavelength for its calculation at standard atmospheric pressure e.g. Equations 5 and 6.

$$\tau_{Ro} = 0.008569\lambda^{-4} (1+0.0113\lambda^{-2} + 0.00013\lambda^{-4}) \quad (5)$$

(Gordon et al., 1988)

$$\tau_{Ro} = 0.00838\lambda^{-(3.916 + 0.074\lambda + 0.050/\lambda)} \quad (6)$$

(Fröhlich and Shaw, 1980)

There is a dependence of τ_R on surface pressure and this dependence can be incorporated in to the calculation of τ_R as in Equation 8.

$$\tau_R = P/P_o \ \tau_{Ro} \quad (7)$$

where

P = surface pressure (mb)
P_o = standard atmospheric pressure, 1013.25 mb
τ_{Ro} = optical thickness at standard atmospheric pressure
(From, Gordon, et al., 1988).

Correcting for surface pressure would require surface pressure as an input into the processing of MODIS data. Surface pressure could be obtained from the National Meteorological Center (NMC).

Ozone

Ozone is an absorber of radiation concentrated in a layer between 20 - 50 km above the surface. There are strong ozone absorption bands lying between 0.2-0.3 μm, and strong bands at 9.6 μm and 14 μm and a weaker band centered about 0.6 μm named the Chappuis band, that could be of concern to terrestrial vegetation studies as this absorption band lies in the red region utilized for vegetation indices. The Chappuis band is a weak ozone band over the wavelengths 0.4-0.8 μm. Because of the location of the ozone layer, above other atmospheric constituents discussed here, absorption by O_3 could be accounted for by determining its absorption, if the concentration of O_3 was known, and its absorption subtracted.

Total O_3 may be measured directly or estimated, based upon known climatology. It may be possible to use the O_3 concentration determined with MODIS by the atmospheric scientists, as Total Column Ozone has been identified as a potential Atmosphere Core Data Product. Other sources of ozone data are given in Table 1.

Surface Reflectivity

The amount of radiation reflected from the surface in any band is determined by the amount of total incident irradiance and the spectral reflectivity, ρ, of the surface. The surface spectral reflectivity can be expressed as a ratio of reflected to incident radiation in a given band:

$$\rho = L_s/F_o \tag{8}$$

where

ρ - is reflectivity, wavelength dependent
L_s - here, is the amount of reflected radiation at the surface, it will be altered by transmission through the atmosphere
F_o - is total irradiance (direct + diffuse) on the surface

Indicated here is a need to know surface reflectivity and total irradiance on the surface in order to determine the amount of radiation reflected from the surface, which is the quantity L_s, that eventually reaches the sensor. The direct and diffuse components of F_o may be determined from the extraterrestrial irradiance (look up tables a possibility) and atmospheric effects.

Summary

This basic framework for an algorithm of atmospheric corrections needed to produce land-leaving radiance has identified what data describing the atmosphere is needed, potential sources of this data, and the current state of development of corrections for Rayleigh, aerosols, and ozone effects over land surfaces. Of these three atmospheric effects, determination of aerosol amounts poses the greatest problem. Corrections for ozone absorption and Rayleigh scattering are faily well established, and are in operational use for ocean color, it may be possible to use some of these methods for correction over land.

The framework for atmospheric corrections is expected to further develop as corrections and algorithm requirements are studied by Science Team members. Presently it may also be used for figuring sizing requirements and processesing scenarios for Land Core Data Products.

TABLE 1
Data Required and Possible Sources of that Data for Atmospheric Corrections over Land Surfaces

The basic relationship is: $L = L_s t_s + L_p$

L - radiance measured at sensor, radiometrically corrected ($Wm_{-2}\mu m_{-1}sr_{-1}$)

L_s - is radiation reflected from the surface, determined by F_o and ρ

DATA NEEDED:

F_o - total irradiance (direct + diffuse) on surface.
Data source: Solar extraterrestrial radiation from look up tables computed for solar zenith angles, observation zenith angles, azimuth, and atmospheric characteristics

ρ - surface reflectivity
Data source: not specified

t_s - is atmospheric effect on transmittance of direct beam.

DATA NEEDED:

τ_R - Rayleigh optical thickness; determined from surface pressure measurements.
Data source: National Meteorologic Center (NMC) surface pressure maps.

τ_A - Aerosol optical thickness; determined by the amount of aerosols present at time of image acquisition.
Data source: Aerosol climatology
Surface visibility measurements, NMC
Atmospheric sampling
MODIS-N, Aerosol Optical Depth; a listed core data product in the Atmospheric Core Data Product Analysis
Note: Determination of aerosols is the greatest unknown in atmospheric corrections over land surfaces.

τ_O - Ozone optical thickness; determined from the amount of ozone present.
Data source: MODIS-N, Total Column Ozone, a listed core data product in the Atmospheric Core Data Product Analysis
Other satellites; Total Ozone Mapping Spectrometer (TOMS)

L_p - is path radiance, the contribution of scattering by Rayleigh and aerosols to L.

DATA NEEDED:

τ_R - same as above
Data source: same as above

τ_A - same as above
Data source: same as above

Note: the optical thicknesses are used in calculating the scattering and phase functions.

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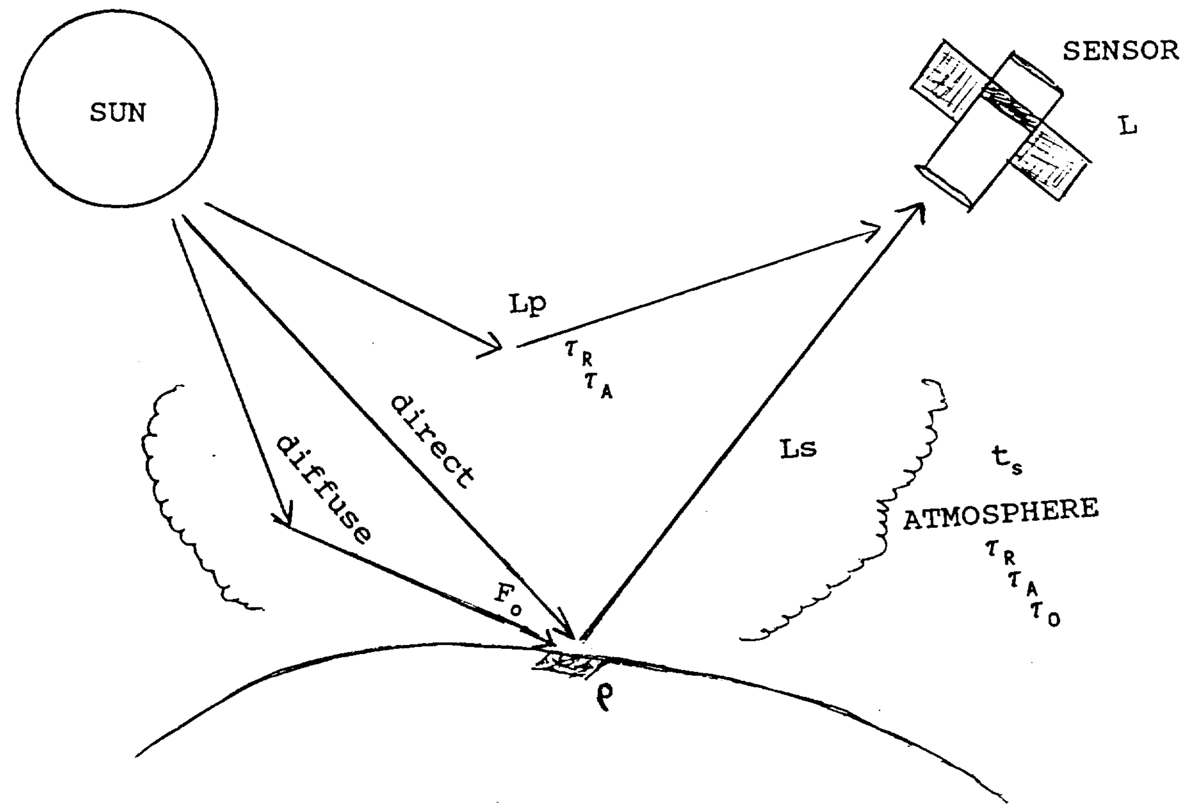

Figure 1. Diagram of components of radiance, L, reaching the sensor.

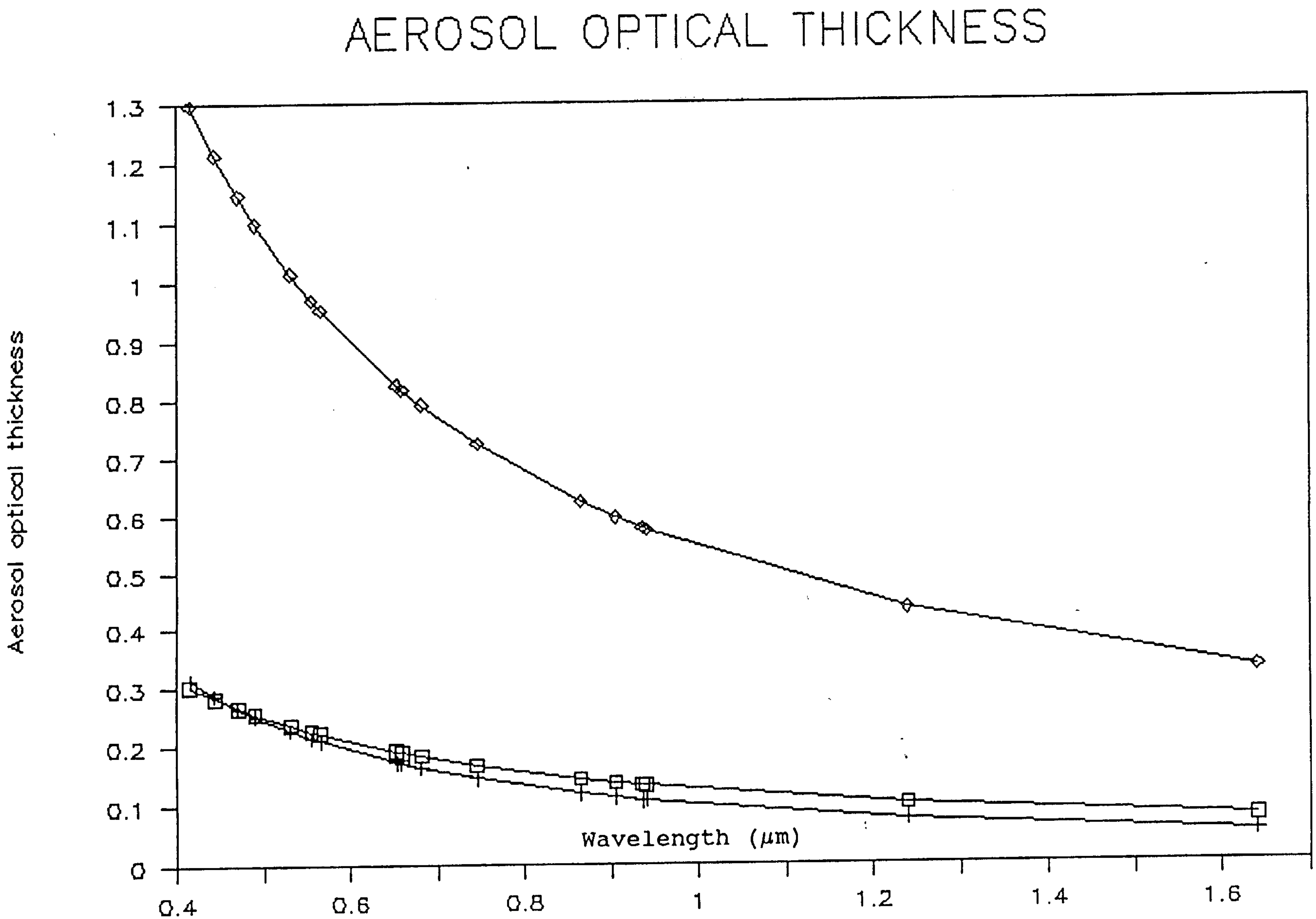

Figure 2. Differing methods of calculating aerosol optical thickness. Angstrom formula; clear atmosphere (open squares), hazy atmosphere (open diamonds), and by Eq.3 (+).